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Constructing Ventilation Bulkheads With Shotcreted Wire Panel

By K. Robert Dorman and Jan G. Patricio

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONSTRUCTING VENTILATION BULKHEADS WITH SHOTCRETED WIRE PANEL

by

K. Robert Dorman[1] and Jan G. Patricio[2]

ABSTRACT

This Bureau of Mines report describes laboratory and field experimentation in building mine ventilation stoppings, air-door frames, and fan bulkheads with a civil construction technique. Shotcrete is applied to a free-standing, three-dimensional wire-truss panel, which is easily cut and rapidly erected. In mines where shotcrete equipment is available, this technique should be faster and cheaper than conventional block-and-mortar or monolithic concrete construction.

INTRODUCTION

The increasing use of diesel equipment, deeper and more expansive workings, and stricter Federal regulations require the installation and maintenance of more sophisticated ventilation systems in underground mines. As a mine expands, ventilating or isolating older workings becomes increasingly difficult, and the integrity of the bulkhead system significantly affects ventilation efficiency. Air leakage in many mines approaches 70 percent of intake.[3]

Though costly, good ventilation is worthwhile because it reduces exposure to health hazards, such as silica or radon, and improves worker safety and efficiency. In searching for ways to decrease the cost of building effective ventilation stoppings, frames, and bulkheads, the Bureau of Mines investigated the civil construction technique of erecting buildings by applying shotcrete to free-standing wire panels. This report describes physical properties testing, laboratory application trials, and two underground installations using shotcreted, commercially available wire panel to build ventilation structures. The underground installations were made with the cooperation of the Bunker Hill Company and the Sunshine Mining Company of Kellogg, Idaho.

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[3]Kingery, D. S. Introduction to Mine Ventilating Principles and Practices. BuMines Bull. 89, 1960, 54 pp (p. 22).

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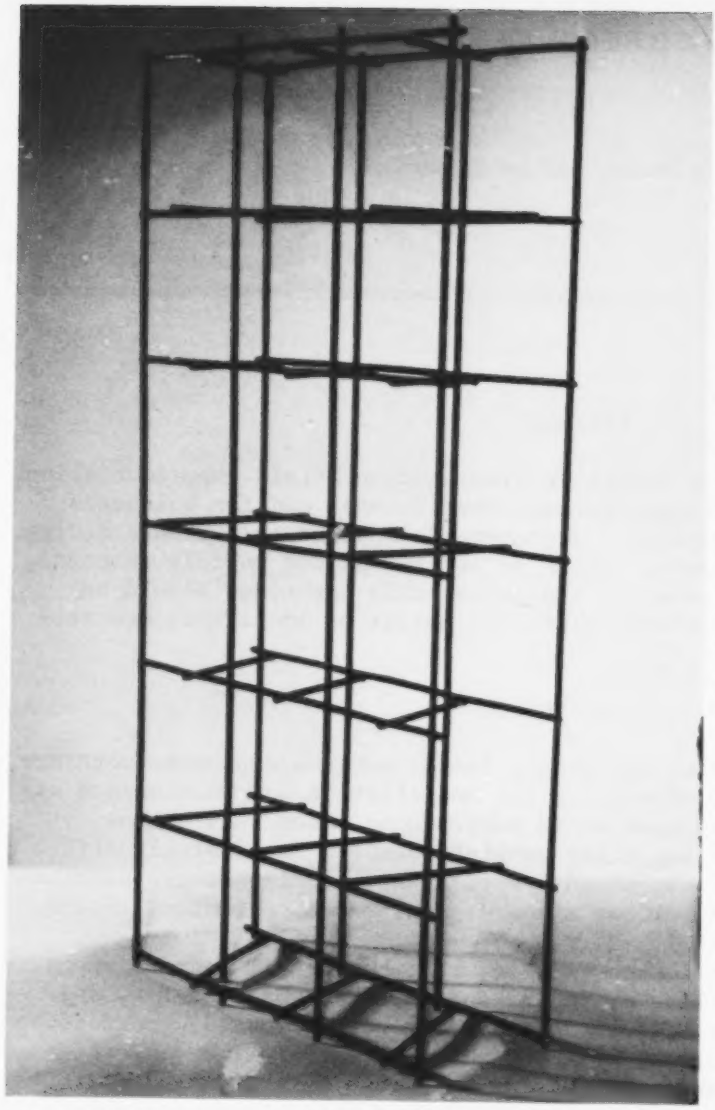

FIGURE 1. - A section of W-panel (6 x 12 x 2 inches).

LABORATORY TESTS

Underground ventilation structures are subjected to bending forces from differential air pressure, concussion from blasting, and compressive loads from the surrounding rock. The laboratory test program was designed to measure the flexural and compressive strengths of structural slabs built by applying shotcrete to commercially available W-panel.[4] Procedures followed the American Society for Testing and Materials (ASTM) specifications 78-64 and 39-71 for third-point flexural and uniaxial compression testing. Flexural tests were made with 1-foot-wide by 4-foot-long beams, and compressive-column tests with 1-foot-wide by 2-foot-high columns. The dimensions were selected to represent small columns, but were sufficiently large to model the influence of minor anomalies in aggregate sizing or reinforcement occuring in field installations. A third type of tests, compressive-strength tests, were also run on 3- by 6-inch cored cylinders.

Five series of laboratory tests were made using 2- and 3-inch W-panel, different shotcrete mixes, wire-fiber shotcrete reinforcement, and a commercial fiber-reinforced concrete mix.

Materials

The construction material, W-panel, is patented under U.S. Patent No. 3,305,981. It is manufactured by forming and welding high-tensile-strength wire into a three-dimensional space frame that utilizes a truss design for strength and stiffness (fig. 1). W-panel is made and sold by CS&M, Inc.,

[4]Reference to specific trade names or manufacturers is made for identification only and does not imply endorsement by the Bureau of Mines.

Rt. 1, Chino Airport, Chino, Calif. 91710. The 2- and 3-inch-thick panels are 4-feet wide, in lengths that range from 6 to 16 feet, in 4-inch increments.

For the civil construction industry, a layer of polyurethane foam is suspended within the frame. The foam serves as insulation and backing for subsequent guniting. After the panels are wired together in the desired configuration, they are gunited to create a reinforced concrete building. The polyurethane core is optional and should be eliminated for underground applications.

The first four laboratory tests were made with shotcrete containing the following ingredients per cubic yard:

(1) 7 sacks of type 1 Portland cement,

(2) 1,000 pounds of fine sand,

(3) 1,100 pounds of coarse sand,

and (4) 700 pounds of pea gravel.

The pea gravel was comprised of minus 3/8-inch material for tests 1, 2, and 4 and minus 1/2-inch material for test 3. In test 4, 75 pounds of 3/4-inch, 16-mil steel fibers were added manually for each cubic yard of shotcrete at the hopper to increase flexural strength. Test 5 was made with a commercial product of shotcrete and wire fibers. In all tests, water was added at the delivery-hose nozzle in amounts dictated by the operator's judgment. Only in test 4 was a small amount of water introduced just ahead of the shotcrete machine hopper to suppress dust.

Equipment

For all laboratory tests, material was applied by a local contractor using a dry-process Reed LOVA II shotcrete machine and portable compressor. The 4-1/2- by 5-foot wooden test-specimen forms were composed of a plywood back and sides of 2- by 6-inch lumber (fig. 2). The forms were designed so that they could be moved into an environmental curing chamber 48 hours after shooting. The W-panel was held exactly in the center of the forms with piano wire through the sides. The forms were tipped 15° from vertical to facilitate applying the shotcrete perpendicularly to the form. A diamond blade cut-off saw was used to trim the edges from the test specimen and cut slabs for the flexural and compressive-column testing. For the compressive-strength tests, however, 6-inch-diameter cylinders of hardware cloth were shot and later cored with a radial-arm drill press and 3-inch-diameter diamond-coring bit. All testing was accomplished in a 400,000-pound Tinius Olsen universal tester, and Hydrostone capping was used on all load-bearing surfaces. A sample readied for compressive-column testing and a beam subjected to flexural loading are shown in figures 3 and 4, respectively. All flexure tests were made using three-point loading (ASTM 78-64) and a span length of 42 inches.

FIGURE 2. - Forms for shotcreted W-panel specimens.

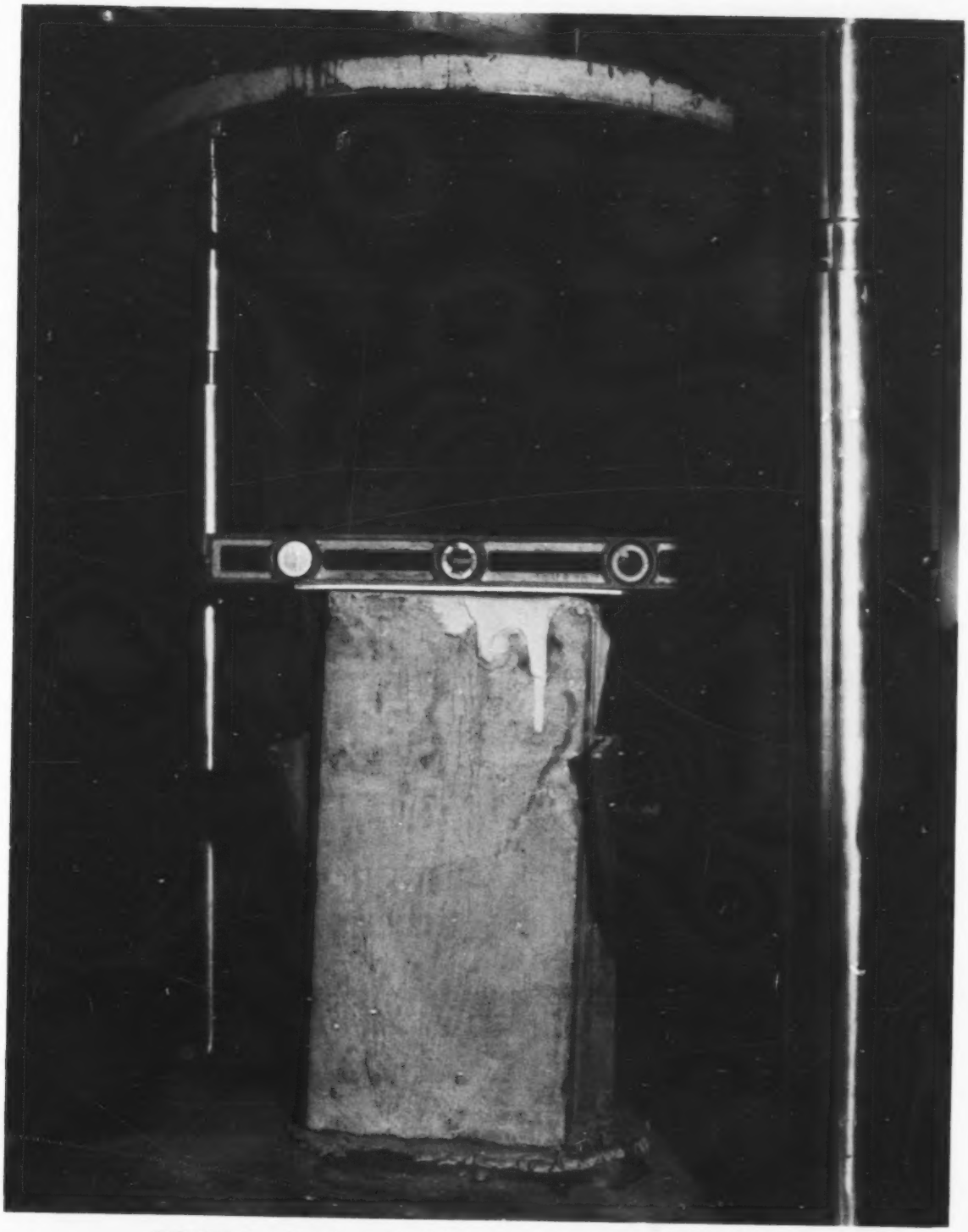

FIGURE 3. - Sample readied for compressive-column strength test.

FIGURE 4. - Beam being tested for flexural strength.

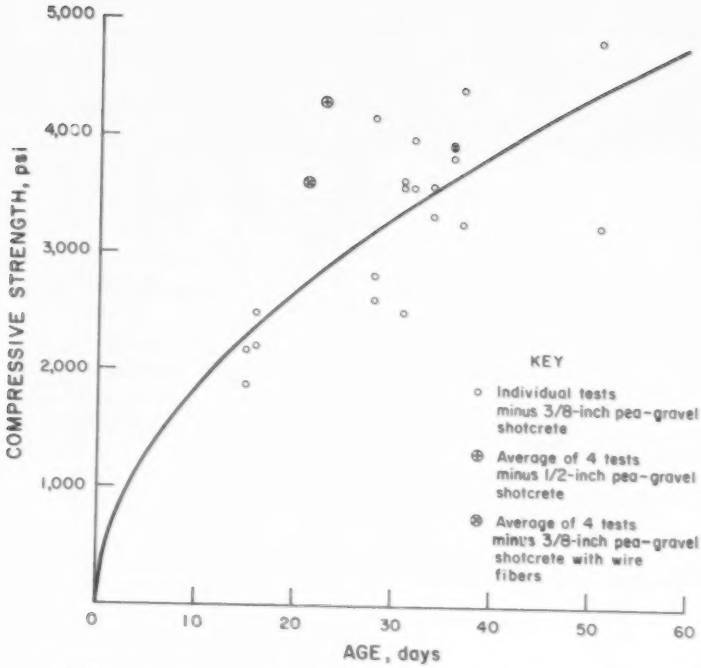

FIGURE 5. - Compressive-column strength of minus 3/8-inch pea-gravel shotcrete.

Curing

Within 30 minutes after application, the specimens were screeded and covered with damp burlap, which was wetted twice a day for the next 48 hours. At the end of this 2-day period, the forms and encased specimens were moved into an environmental room, which was maintained at 70° F and 90 to 95 percent relative humidity. Upon removal from this room, the forms were stripped and the test specimens were trimmed and sawed into slabs of desired sizes for flexural and compressive-column strength testing. The slabs were then stored in a fog room at 70° F and 100 percent humidity until testing.

Test Results

Compressive-column strengths are listed in table 1; flexural strengths, in table 2; and the 60-day compressive strengths of 3- by 6-inch cylinders, in table 3. The compressive-column strength curve in figure 5 is drawn using data from both tests 1 and 2, as the mix and curing conditions were identical. The curve, which was fitted to the data using a power function, has an index of determination of 0.583. Average values for the shotcretes containing minus 1/2-inch pea gravel and minus 3/8-inch pea gravel with wire fibers added are plotted for comparative purposes.

TABLE 1. - Compressive-column strengths

Age, days	W-panel size, in	Bearing area, in^2	Ultimate load, lb	Compressive strength, psi
TEST 1 (MINUS 3/8-INCH PEA-GRAVEL SHOTCRETE)				
15	3	48	90,000	1,875
15	3	48	104,000	2,170
16	3	48	119,500	2,490
16	3	48	105,750	2,205
Average	-	-	-	2,185
28	3	48	125,000	2,605
28	3	48	134,750	2,810
Average	-	-	-	2,710
36	3	48	183,500	3,820
36	3	48	187,750	3,910
36	3	48	188,500	3,930
37	3	48	156,500	3,260
37	3	48	194,000	4,400
Average	-	-	-	3,860
TEST 2 (MINUS 3/8-INCH PEA-GRAVEL SHOTCRETE)				
28	3	48	199,500	4,155
31	3	60	217,500	3,625
31	3	60	150,000	2,500
31	3	60	214,000	3,565
32	3	60	238,500	3,975
32	3	54	192,500	3,565
34	2	54	179,500	3,325
34	3	60	214,500	3,575
Average	-	-	-	3,535
51	3	54	260,000	4,815
51	3	60	194,000	3,235
Average	-	-	-	4,025
TEST 3 (MINUS 1/2-INCH PEA-GRAVEL SHOTCRETE)				
21	3	54	276,500	5,120
21	3	60	179,000	2,985
25	3	60	228,250	3,805
25	3	48	249,000	5,190
Average	-	-	-	4,275
TEST 4 (MINUS 3/8-INCH PEA-GRAVEL SHOTCRETE WITH WIRE FIBERS)				
21	2	54	179,600	3,325
21	3	54	217,500	4,025
21	3	54	230,000	4,260
21	2	54	149,000	2,760
Average	-	-	-	3,590

TABLE 2. - Flexural strengths

Age, days	W-panel size, in	Beam size		Ultimate load, lb	Modulus of rupture,[1] psi
		Depth, in	Width, in		
TEST 1 (MINUS 3/8-INCH PEA-GRAVEL SHOTCRETE)					
15.....	3	4	12	1,910	438
15.....	3	4	12	2,000	418
Average.	-	-	-	-	428
56.....	3	4	11.5	3,000	685
59.....	3	4	11.75	3,000	670
59.....	3	4	11.5	2,850	650
59.....	3	4	11.75	3,200	715
Average.	-	-	-	-	680
TEST 2 (MINUS 3/8-INCH PEA-GRAVEL SHOTCRETE)					
7.....	3	4	12	1,820	400
TEST 3 (MINUS 1/2-INCH PEA-GRAVEL SHOTCRETE)					
27.....	3	4	12	1,750	385
27.....	3	4	12	2,600	570
27.....	3	4	12	2,060	450
Average.	-	-	-	-	470

[1] $R = pl/bd^2$

where R = modulus of rupture, psi,
P = maximum load, lb,
l = span length, in,
b = average width, in,
and d = average depth, in.

TABLE 3. - Sixty-day 3- by 6-inch cylinder strengths[1]

Failure load, lb	Compressive strength, psi	Failure load, lb	Compressive strength, psi
49,200	6,960	47,400	6,705
36,700	5,190	53,100	7,510
49,300	6,975	48,000	6,790
37,000	5,235	45,600	6,450
45,900	6,495	47,400	6,705
		Average	6,500

[1]Cylinders made from test 2 samples.

Experience with the commercial product containing wire fibers was so unsatisfactory that meaningful data was unobtainable. For this reason, the results of test 5 are not reported. The problems encountered may have been due to faulty application procedures, rather than material properties. The typical failure patterns (figs. 6-8) show that the W-panel reinforcement preserved the structural integrity of the slabs after crushing and cracking.

FIGURE 6. - Beam cracked from flexural loading.

FIGURE 7. - Completely failed beam with reinforcing wire exposed.

FIGURE 8. - Failed columns maintained by reinforcing wire.

UNDERGROUND INSTALLATIONS

After completion of laboratory testing, the Bureau signed cooperative agreements with the Sunshine Mining Company and the Bunker Hill Company of Kellogg, Idaho, to try the shotcreted W-panel method in building underground ventilation structures.

Fan Bulkhead Construction

In the Sunshine mine, shotcreted W-panel was used to relocate a ventilation fan on the 3700 level. The 5-1/2- by 7-1/2-foot fan adapter plate, which included a man door, was placed in a drift of approximately 8-1/2 by 10-1/2 feet and bolted to the mounted fan. Edges of back-to-back strips of 3-inch W-panel, with a layer of burlap sandwiched between, were placed against the ribs, back, and sill, and squeezed into the 6-inch channel that framed the adapter plate (fig. 9). Wire ties were used along seams and through the layers to produce a monolithic W-panel unit. A snug fit eliminated any need for anchoring to the walls.

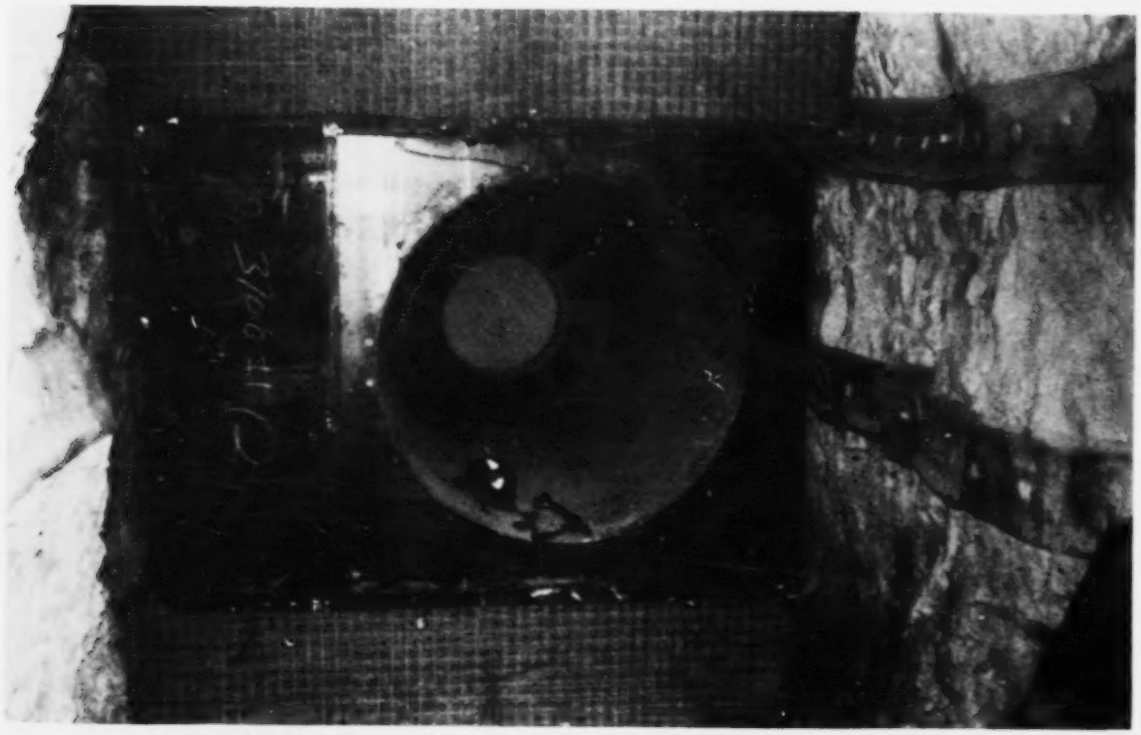

FIGURE 9. - W-panel in place at top and bottom of adapter plate.

The shotcrete mix was applied to the W-panel from alternate sides, using a wet process machine, to create an 8-inch-thick bulkhead. The nine-sack shotcrete mix, packaged in 65-pound plastic-lined paper bags, contained the following incredients per cubic yard:

Cement (type 1-A).....	846 pounds
Fine sand.....	891 pounds
Coarse sand (minus 1/4-inch)	1,782 pounds

Water was added according to the operator's judgment. The nine-sack mix was chosen because it had been used previously by both cooperating mining companies.

The cost for W-panel and shotcreting was--

160 bags shotcrete (80 ft^3) @ $2.39 per bag (including freight)	= $382.40
Three 3-inch W-panels (4 feet by 8 feet) @ $42.00 per panel (includes freight)	= 126.00
Burlap (estimated cost)	= 10.60
	519.00

One-half man-shift was spent fitting the W-panel and 2-1/2 man-shifts applying the shotcrete. Neither travel nor lunchtime is reflected in the labor for fitting the W-panel, because the crew was already working on the level.

The 200-hp, two-stage, 42-inch, axial vane fan was put back into operation 44 hours after shotcreting. The ventilation engineer reports that the leakage around the edges is no greater than that experienced with the former monolithic, poured-concrete installation. The pressure drop across the fan has not been determined since the move; however, it was measured in the prior location at 17 inches water gage.

Air Door Construction

Shotcreted W-panel was used for an air door installation on the 21-1/2 level of the Bunker Hill mine. The diesel truck haulageway in the J vein measures approximately 11 feet high by 19 feet wide at the air door. Openings for a rollup air door, man door, and fan were framed in with 8 by 10 and 6 by 10 timbers. Back-to-back 2-inch W-panels, with a layer of burlap sandwiched between, were nailed to the timbers and wired to existing rock bolts to fill the spaces across the back and down both walls. An Eimco wet-process machine was used to apply the shotcrete, which was the same mix as that used in the Sunshine fan installation. Figures 10 and 11 show the structure before and after shotcreting.

The shotcrete was applied to the front and back of the panels on two separate days. This was done because mine personnel felt that the front side might require the waiting time to achieve initial set so that it would not be dislodged when the shotcrete was applied to the back.

FIGURE 10. - W-panel above air-door and fan opening.

FIGURE 11. - Air-door frame after shotcreting.

The cost for the W-panel and shotcreting was as follows:

60 bags (30 ft^3) shotcrete @ $2.39 per bag (includes freight)	= $143.40
Three 2-inch W-panels (4 feet by 8 feet) @ $34.00 per panel (includes freight)	= 102.00
Burlap (estimated cost)	= 10.60
Total	256.00

Four man-shifts were spent erecting the W-panel, and three man-shifts applying the shotcrete. This includes travel to and from the working place, lunch periods, setup time, and machine cleanup. Actual application time for the three-man crew was 45 minutes on each of 2 days.

After shotcreting, a 7-1/2-hp, 32-inch axial vane fan and a 16-gage 8- by 10-foot industrial overhead door (fig. 12) were installed. The garage-type opener is powered by a 440-volt motor and can be opened or closed by a pull-type signal cord from either side. The pressure drop across the door is between 1/2- and 3/4-inch water gage. No weather stripping or skirting is used. Minor leakage occurs between the door and sill.

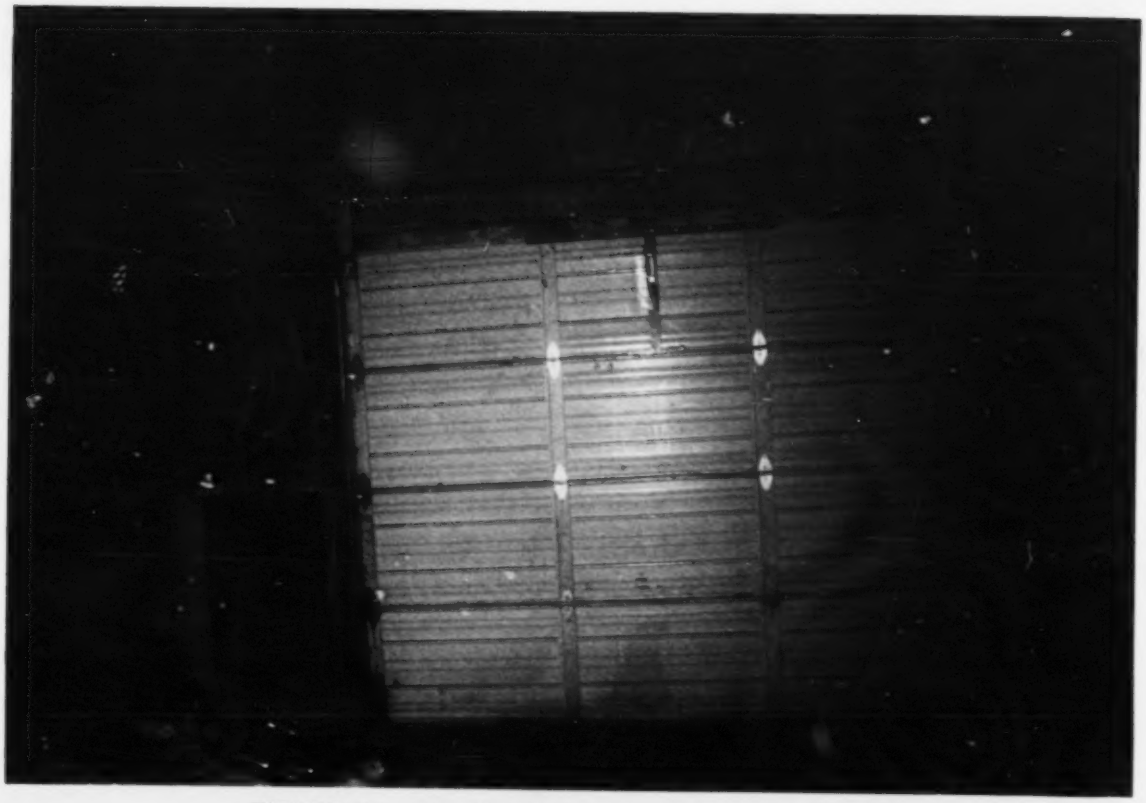

FIGURE 12. - Completed air-door and fan installation.

APPLICATION TECHNIQUE TRIALS

Experience with the underground installations suggested that some variations in application technique be tested in the laboratory. Some questions to be answered were (1) After shotcreting the front side of the sandwich-type (W-panel, burlap, W-panel) bulkhead, can the operator immediately shotcrete the reverse side without dislodging fresh material from the front?, and (2) When sealing a dead-end drift by shotcreting only the near side of the bulkhead, is rigid backing (such as plywood) required, or will a fabric suffice? A quantity of the same minus 3/8-inch, nine-sack shotcrete mix used underground was purchased and a series of laboratory trials begun.

Equipment

A 4-foot-square wood frame, 6 inches in depth, was bolted together and mounted on a plywood base. Angle braces held the frame in a vertical position for the tests. The W-panels were suspended inside the frame by tie wires passed through holes drilled at intervals in the wood. Because the objective was to check application techniques, rather than material properties, facilities for controlled curing and careful moving of test slabs were not required.

Shotcrete was applied with a dry-process SOVA 3 machine, and compressed air was supplied by a 210-cfm truck-mounted LEROI compressor. Best results were obtained with 30 psi applied to the feed motor and 60 to 75 psi to the material-delivery hose. The operator maintained a relatively dry mixture with the manually controlled water valve at the nozzle. A wet mixture will sag once the thickness of the layer exceeds the 2- or 3-inch thickness of the W-panel.

Application Trials

The first trial was made with two 2-inch W-panels with a layer of burlap sandwiched between. For the initial pass, a layer of shotcrete about 1-1/2 inches thick was applied to the front side. After a 10-minute wait, a similar layer was blown on the back, followed immediately by a finish layer on the front and then on the back. The total elapsed time was 25 minutes, and the completed panel averaged 6 inches thick. The only problem encountered was shotcrete sagging on the front side in one area where apparently too much water was used. This indicated that if the water were more carefully controlled, the waiting period following application of the initial layer would be unnecessary.

The second trial was made using a 3-inch W-panel and a layer of burlap wired to the back side at points about 18 inches apart. To simulate possible poor workmanship in an underground application, the burlap was left very loose. Shotcrete was applied from the W-panel side in a continuous 15-minute operation to produce a panel with an average thickness of 8 inches. No problems were encountered. This trial proved that a seal can be made using a continuous application of shotcrete to a W-panel backed with fabric. Loose backing

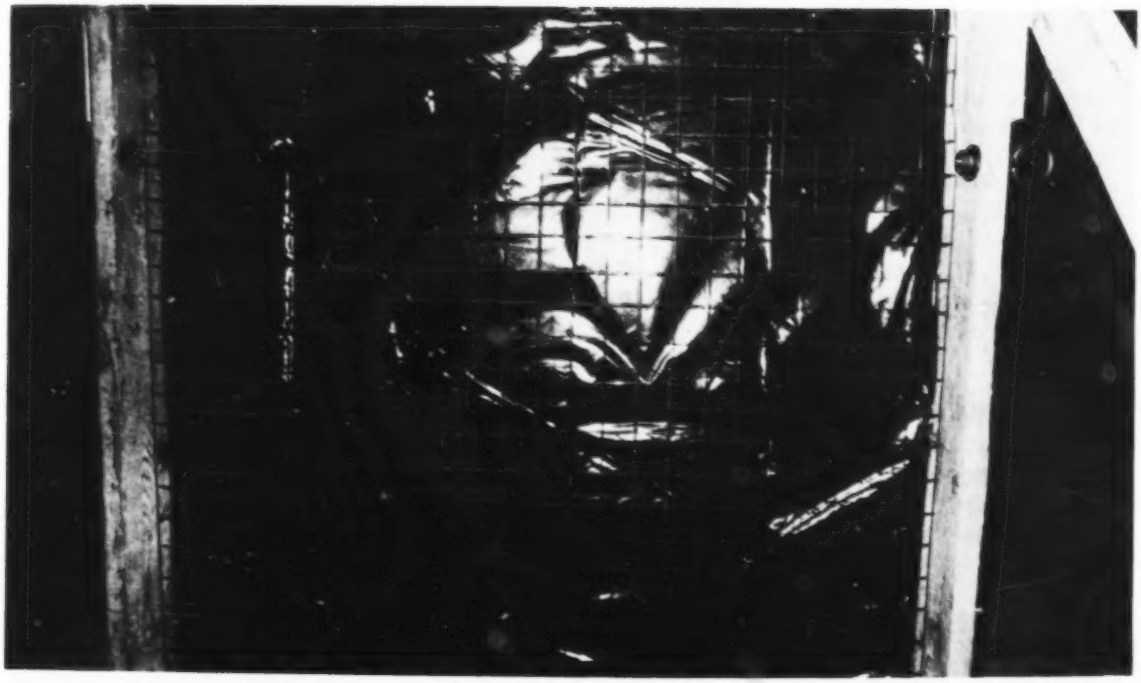

FIGURE 13. - Two-inch W-panel with polyethylene backing.

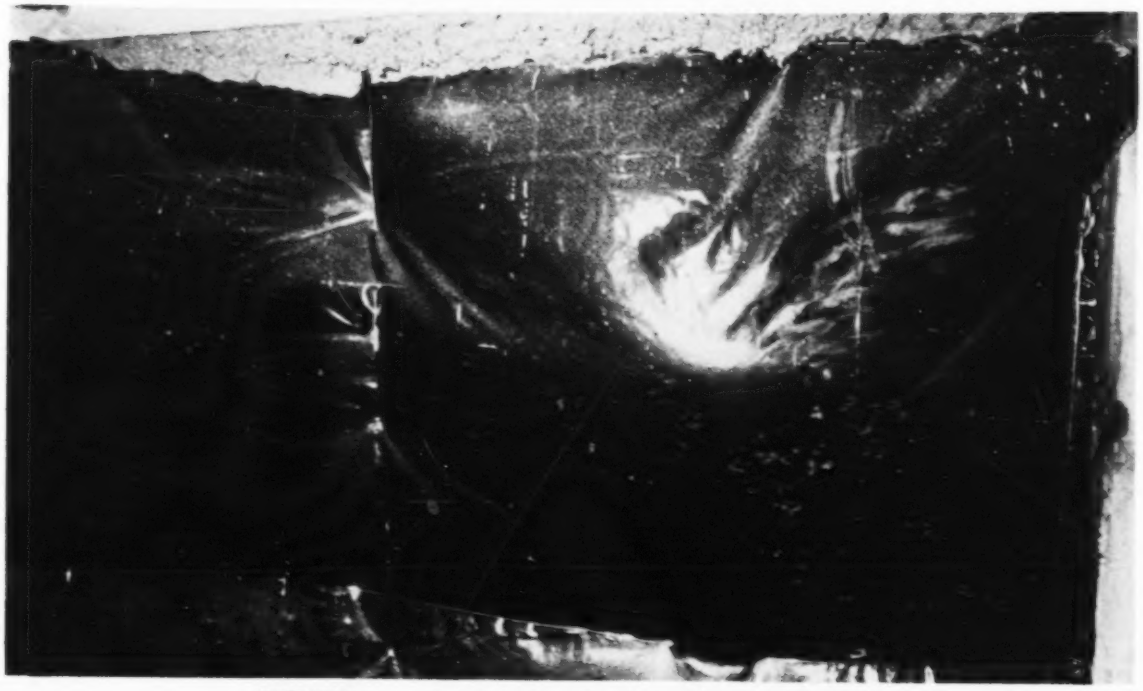

FIGURE 14. - Polyethylene backing after shotcreting.

creates no problem provided that, for the initial pass, shooting is started at the bottom of the structure and is progressively moved upward, only as the voids between the back side of the W-panel and the burlap bulges become completely filled.

The third trial was a repeat of the second but with a 2-inch W-panel and one layer of 6-mil polyethylene backing (fig. 13). As can be seen in figure 14, the backing was laced to the W-panel with 14-gage wire on about 12-inch centers. No problems were encountered--the backing did not tear. The shotcrete shown along the upper edge of the form in figure 14 spilled over the top lacing wire.

The fourth trial was designed to test whether one could apply shotcrete to the front side of a fabric-backed W-panel, remove the backing, and immediately apply a layer of shotcrete to the back. This technique was proposed

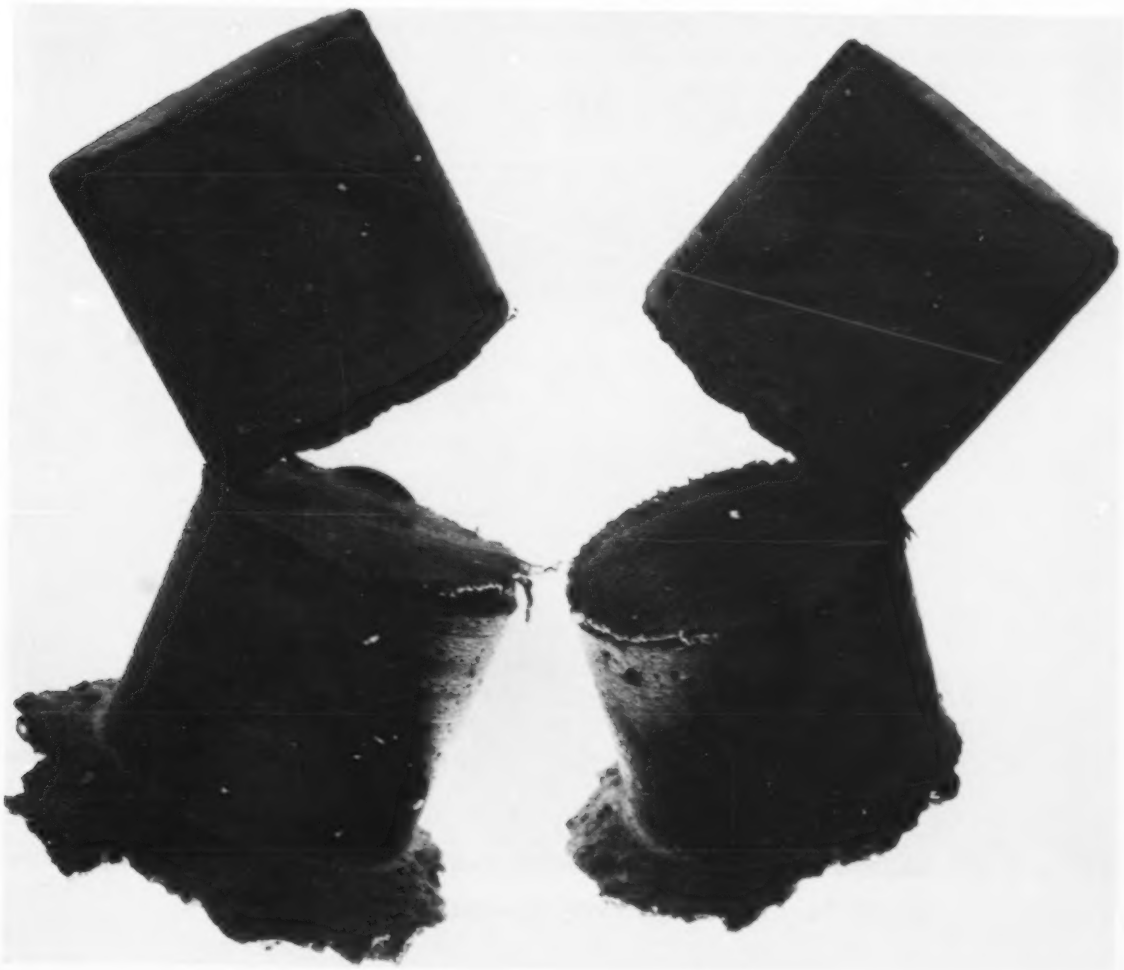

FIGURE 15. - Cores from sandwich-type construction.

after cores were obtained from the first trial slab, which was of the sandwich-type construction. It is evident in figure 15 that the sandwich-type construction produces two separate slabs bonded together only by whatever tie wires are used. For trial 4, a 2-inch W-panel was backed with some scrap fabric that resembles the loosely woven material used for manufacturing large produce bags. As soon as a 2-inch layer of shotcrete had been applied to the front, the backing was removed (fig. 16), and a layer of shotcrete about 1 inch thick was applied to the back. This was followed immediately by a 1-inch-thick finish coat to the front. No problems were encountered.

The fifth, and final, trial was a demonstration for visitors. A vertical divider was nailed in the 4-foot-square form; 2-inch W-panel was placed in the left half, and 3-inch W-panel in the right half. The setup, with burlap backing, is shown in figure 17.

With several consecutive passes, a 3-inch layer was applied to the entire 3-inch panel and to the lower three-fourths of the 2-inch panel. The backing was then removed from the 2-inch panel, and a 1-inch coat immediately applied to the back of that panel. Then a final 1-inch finish coat was applied on the front side of the 2-inch panel, and a 2-inch finish coat was applied on the

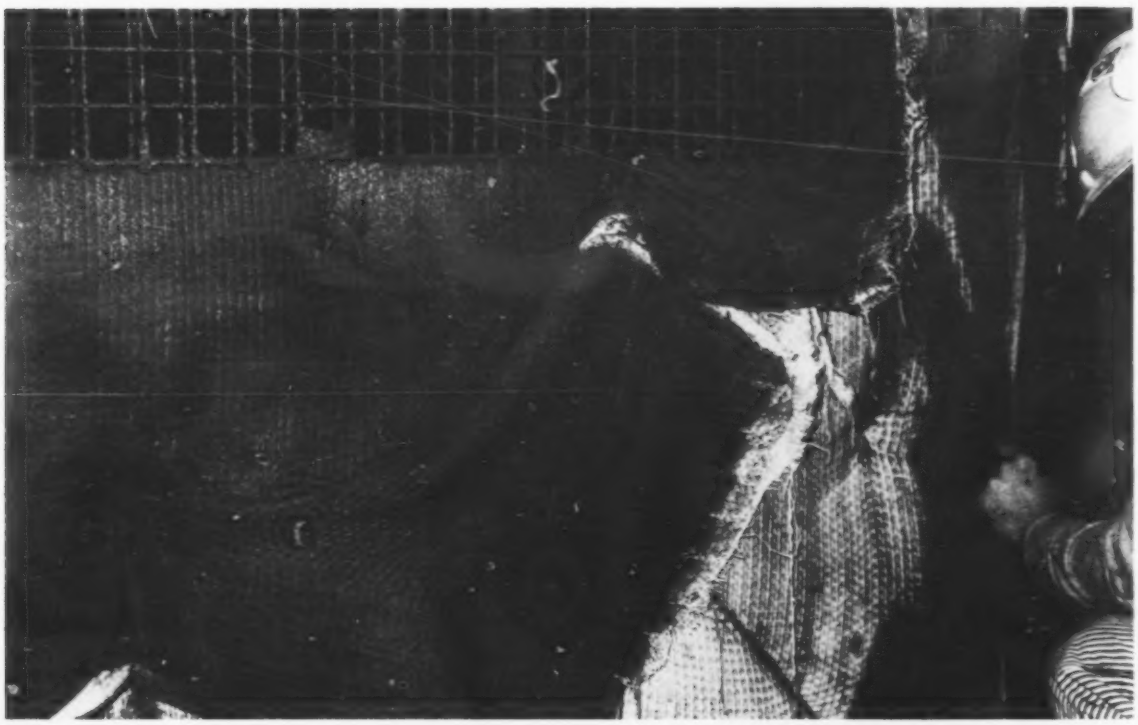

FIGURE 16. - Removing backing from freshly shotcreted W-panel.

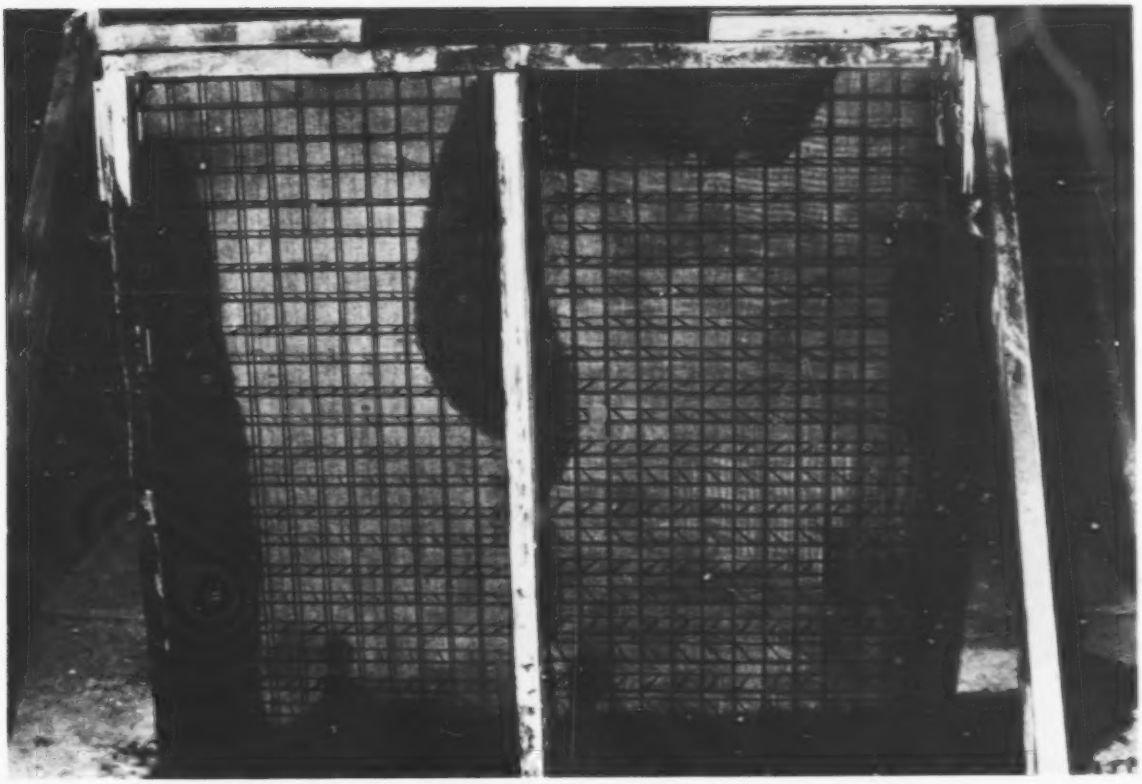

FIGURE 17. - Form divided for demonstration with the 2-inch W-panel on the left and 3-inch W-panel on the right.

3-inch panel. Figure 18 shows the back side of the panels after the finish coat had been applied to the back of the 2-inch panel. Figure 19 is a frontal view of the finished demonstration. Note that, even without the aid of backing material, the finish coat on the back of the 2-inch panel was extended 8 inches above the front-side shotcrete.

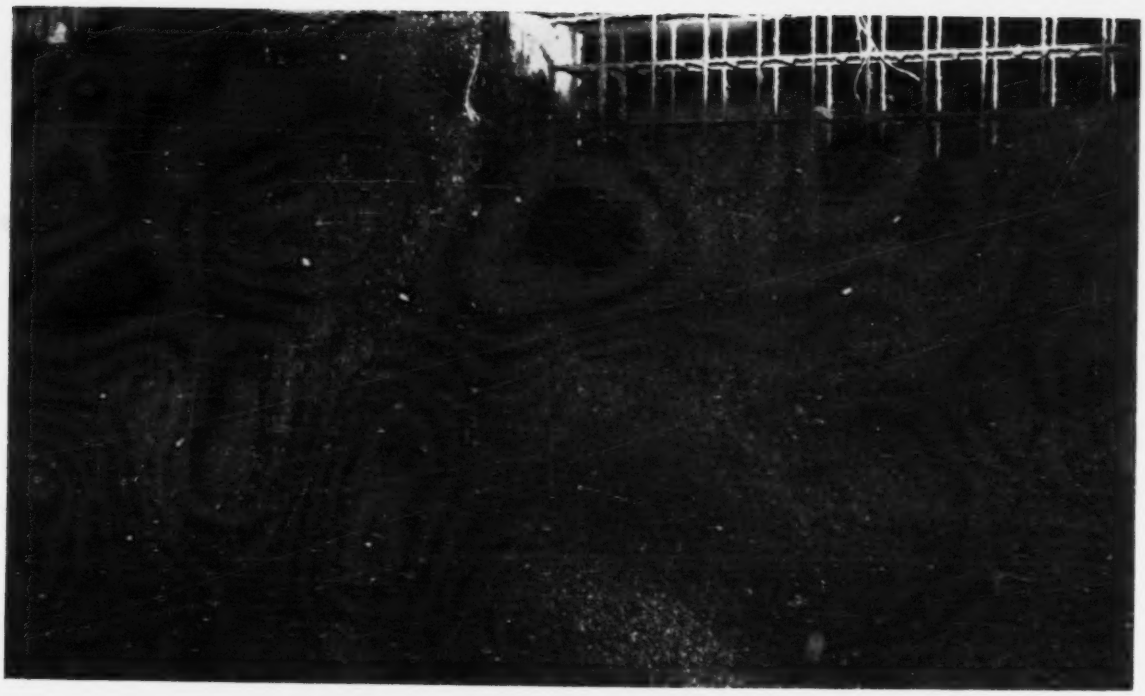

FIGURE 18. - Back of completed demonstration.

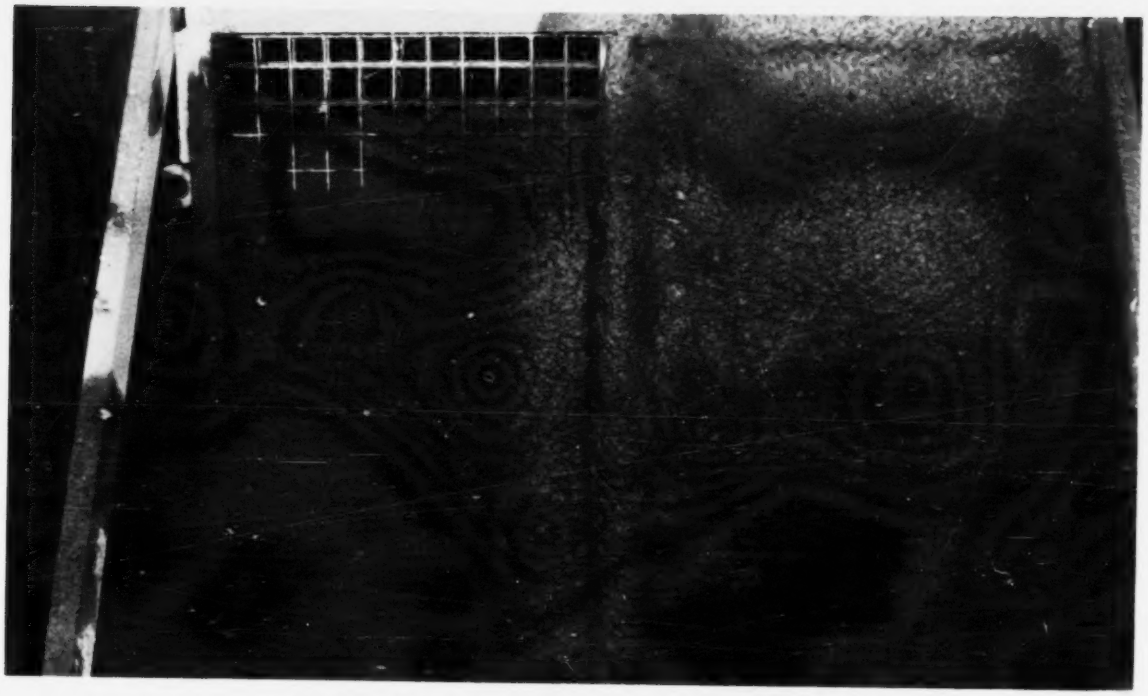

FIGURE 19. - Front of completed demonstration.

Core Strengths

Cores were drilled from three slabs to visually examine placement quality. Voids were found in only one sample, which was taken near the edge of the slab. The cores from trials 2 and 3 were then faced with a grinder, capped, and tested in compression. Values are given in table 4. The slabs and cores were cured at room temperature and ambient humidity.

TABLE 4. - Compressive strengths of application-technique cores[1]

Age, days	Length of core, inches	Failure load, pounds	Compressive strength, psi
TEST 2			
31.....	6	53,600	7,585
31.....	6	56,200	7,950
31.....	6	47,600	6,735
31.....	6	55,500	7,850
Average....			7,530
TEST 3			
28.....	4.5	30,600	4,330[2]
28.....	4.0	42,400	6,000
28.....	4.75	44,100	6,240
28.....	4.25	43,700	6,180
Average....			6,140

[1]Three-inch-diameter cores cured at room temperature and ambient humidity.

[2]This sample contained voids, and was therefore excluded from the average shown.

CONCLUSIONS

Based upon these successful experiences shotcreting W-panel, the following observations and conclusions can be made:

1. The amount of water used is dictated by the appearance and behavior of shotcrete during application. The mixture should be kept relatively dry to prevent slumping. However, a dry mixture produces slightly more rebound.

2. A 6-inch-thick bulkhead can be shot in a continuous operation on alternate sides or one side only.

3. A fabric backing is adequate.

4. For sealing dead-end openings, one layer of 3-inch W-panel and one layer of backing should be used. The shotcrete can be applied all from one side. Although a loose backing will work, taut backing requires less shotcrete.

5. When constructing a bulkhead from both sides, use one layer of 2- or 3-inch W-panel and one layer of backing. Using several passes, apply an initial layer sufficiently thick to completely fill a 2-inch W-panel or nearly fill a 3-inch panel. Remove the backing and apply a finish coat on the back. Complete by applying a finish coat on the front.

6. Work from the bottom up, maintaining a slight lead at the edges.

7. Use several passes for each layer. If the backing bulges, fill the void between it and the W-panel before progressing upward.

8. Hairline shrinkage cracks were observed in the slabs made in the laboratory with the nine-sack mix, indicating that a seven-sack mix is probably a better choice.

9. Follow manufacturer's recommendations for tying together adjacent pieces of W-panel.

10. The wire reinforcement preserves the structure's integrity during initial crushing of the shotcrete. Remove as much loose, broken material as possible and patch with new shotcrete.

11. It is doubtful whether the Bunker Hill installation was cost effective. The shotcrete machine had to be brought from another of the company's properties. The Sunshine mine already had a machine underground. There, the complete installation required much less labor than if the bulkhead had been made with forms and poured concrete or with block and mortar.

The use of shotcreted W-panel for building ventilation structures is a rapid, cost-effective method, particularly if several structures are required, and if a shotcrete machine is readily available.

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